COE for Airworthiness Assurance (AACE)

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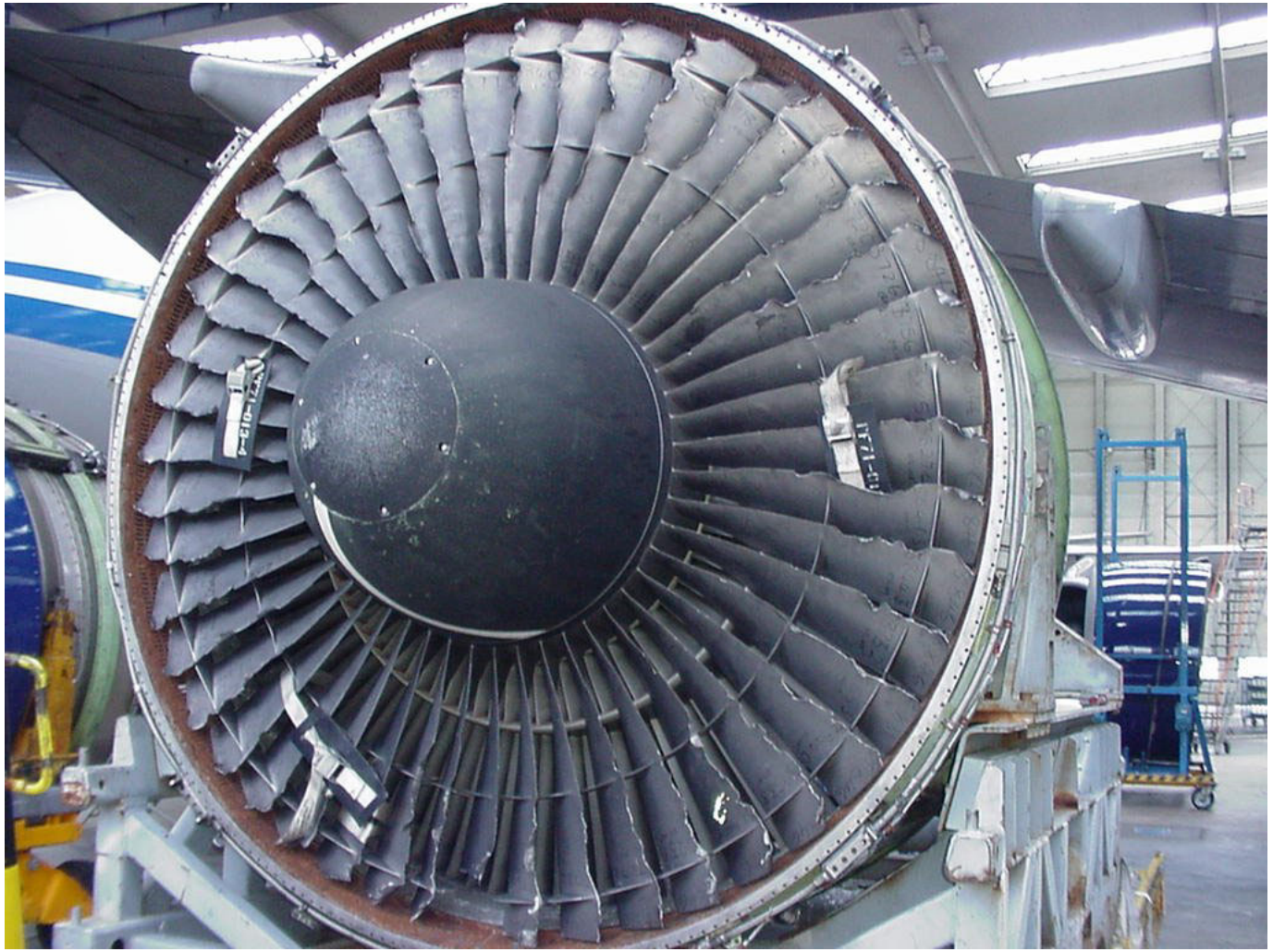
Project Goal

The goal of this project is to combine the technical strengths of Honeywell Engines & Systems Phoenix, SRI International, NASA Glenn Research Center (GRC) and Arizona State University for developing a robust explicit finite element analysis modeling methodology of composite fiber fabric wraps that are widely used in the containment systems of gas turbine engines.

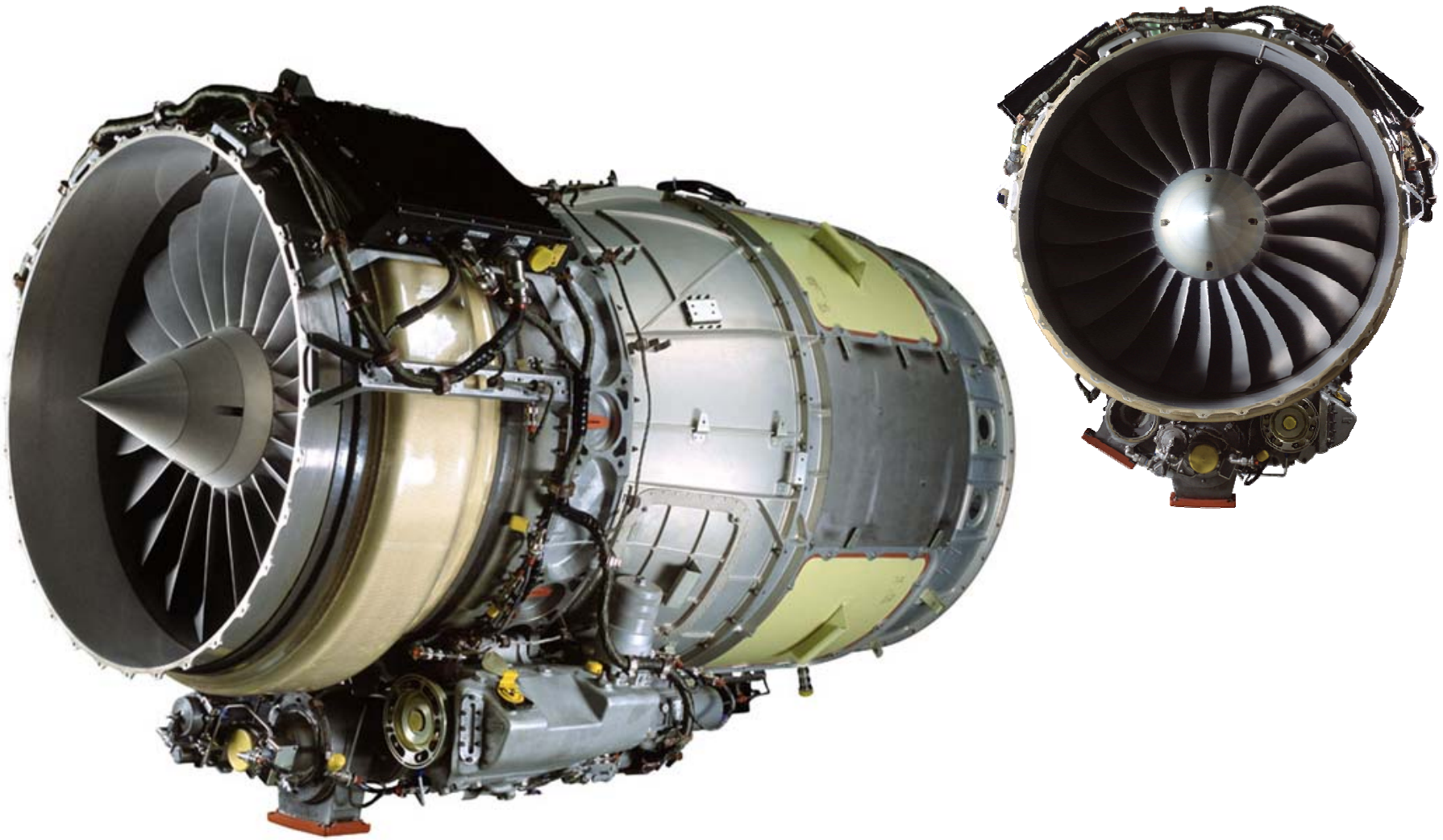
Project History

- Phase 1: Sept 2001 – May 2003
- Phase 2: Oct 2003 – May 2006

The Wrong Way



Honeywell AS907 Turbofan Engine



Phase 1 Tasks

- Development of a material model suitable for both implicit and explicit FE analyses
- Verification of the material model using static and dynamic load tests
- Incorporation of the material model in full-scale engine test models and comparison with full-scale test results

ASU and SRI

Development of Material Model and Verification via Static Ring Tests

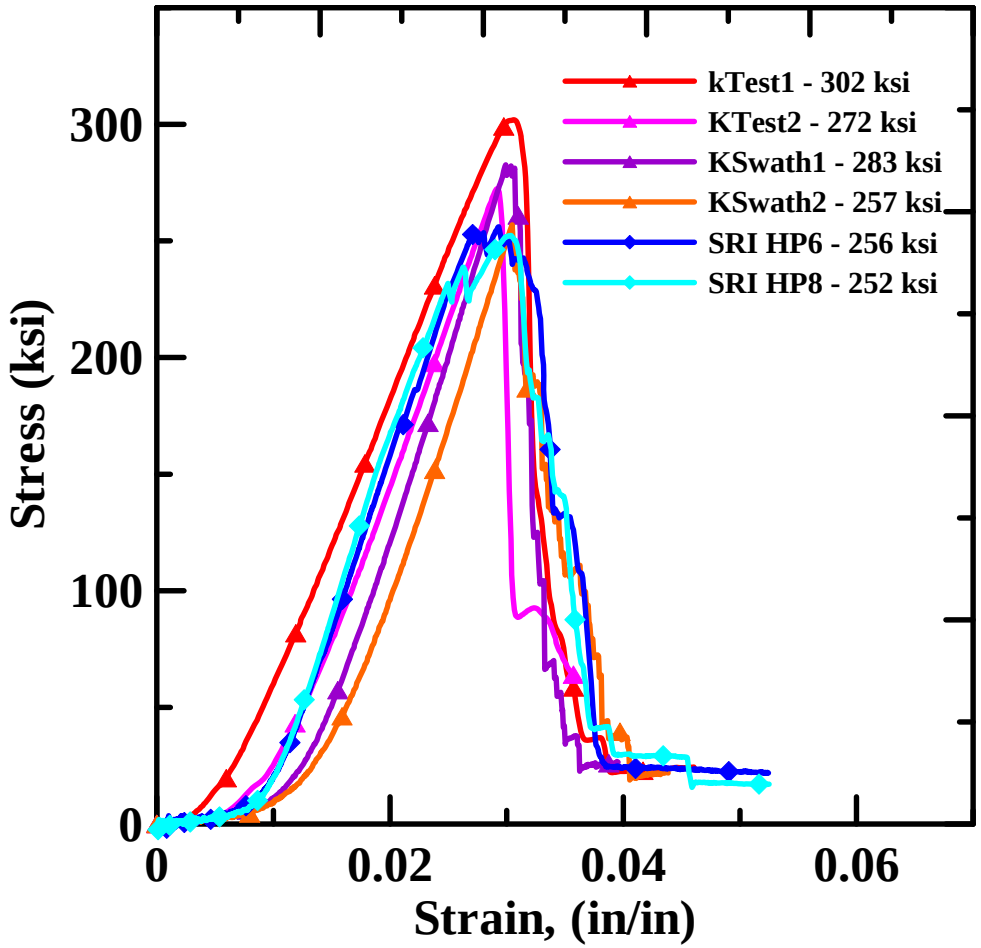
Fabrics Used

	Kevlar 49	Light Zylon AS	Heavy Zylon AS
Yarn Denier (g/9 km)	1500	500	1500
Yarn Count (yarns/in)	17 x 17	35 x 35	17 x 17
Areal Density (g/cm^2)	0.00275	0.01575	0.0223

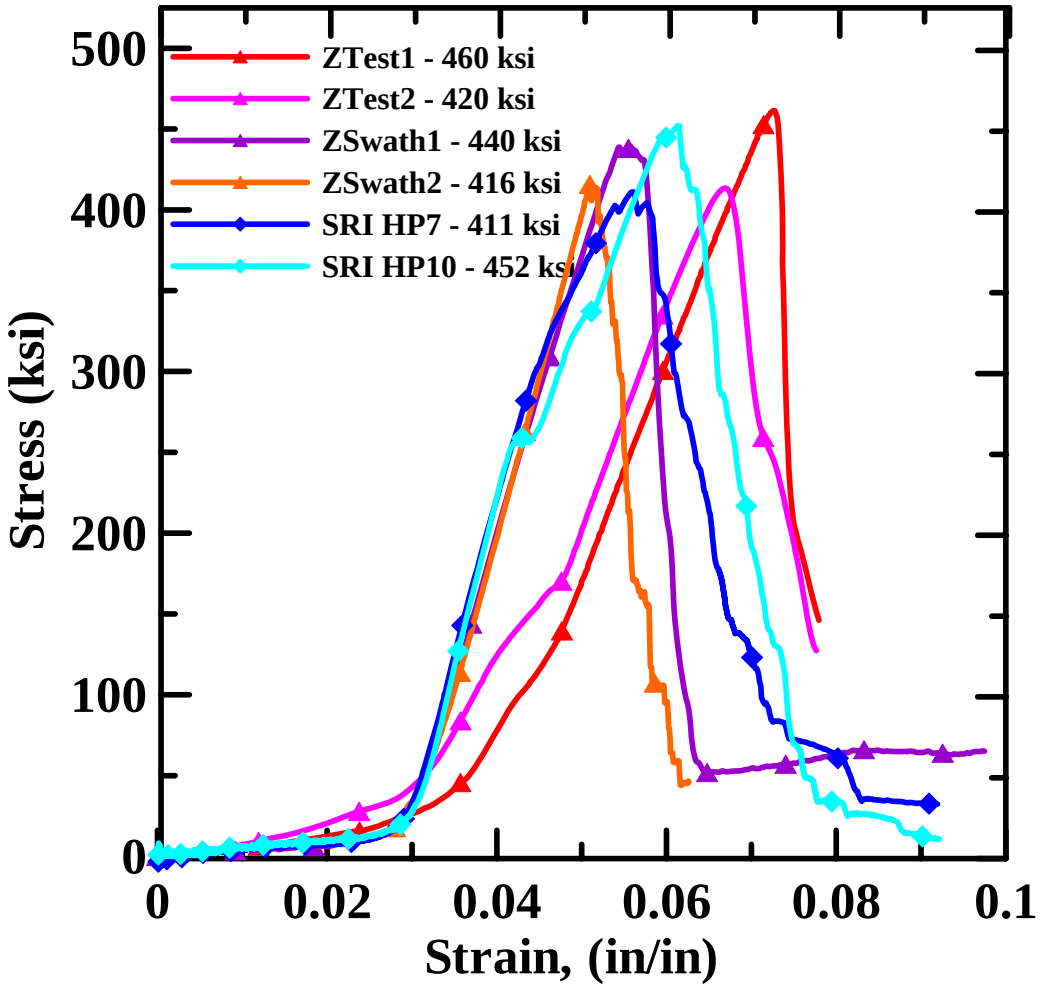
Simple Tension Test

- Specimen: 12” long, 2.5” wide
- End tabs: 2.5” long, 2.5” wide, 0.025” thick
- Actuator stroke rate: 0.1”/min

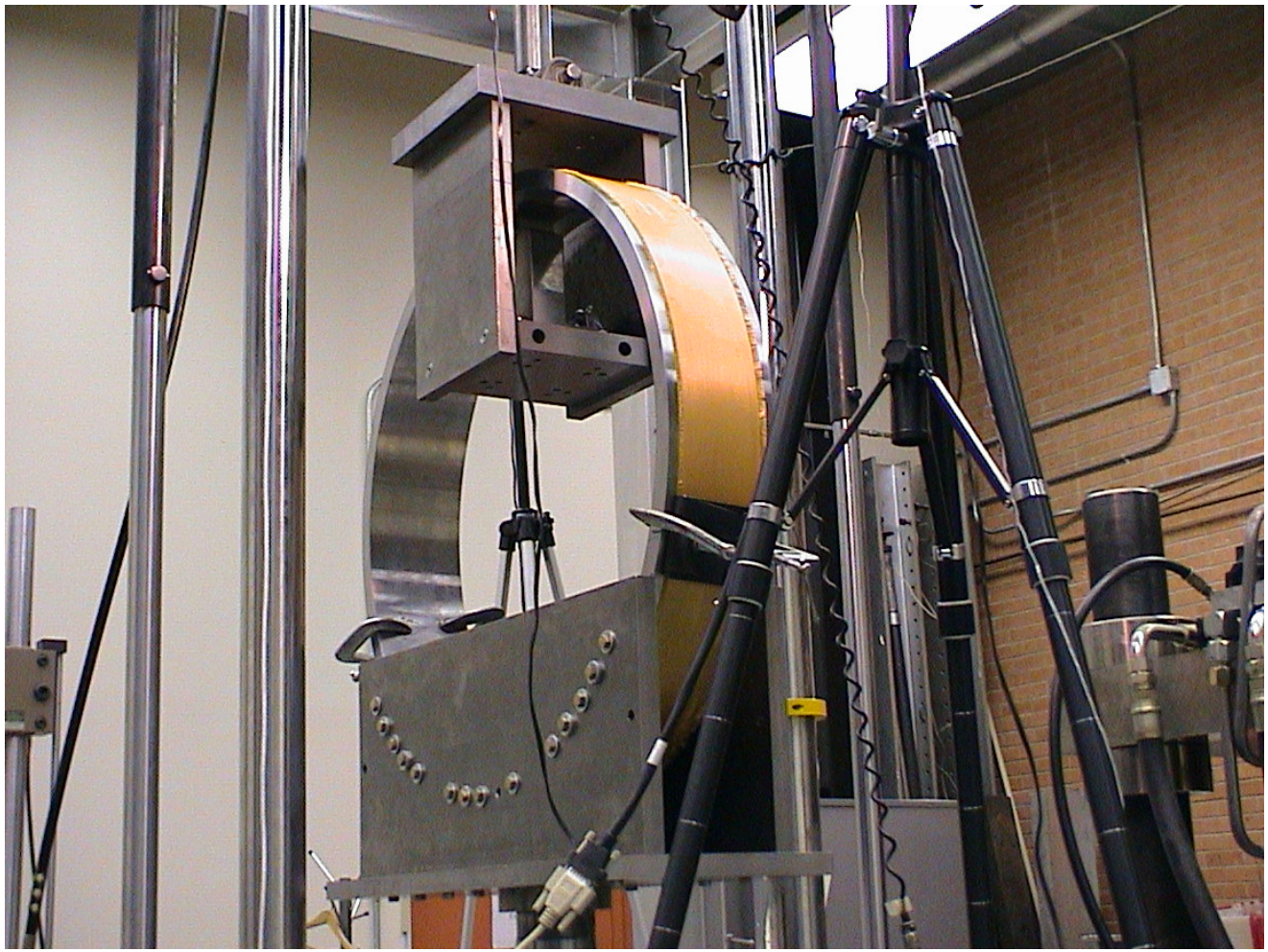
Kevlar Stress-Strain Curves



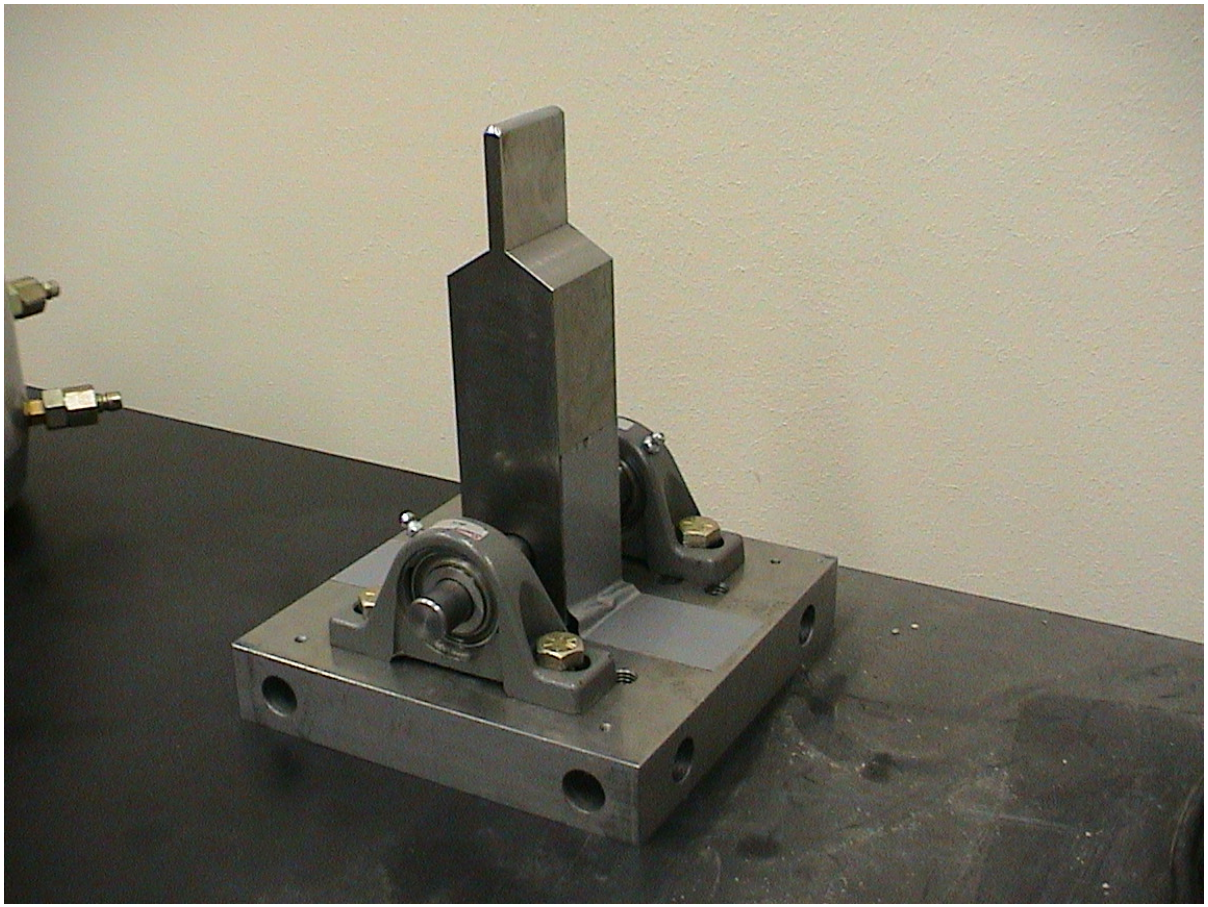
Zylon Stress-Strain Curves



Static Test Setup



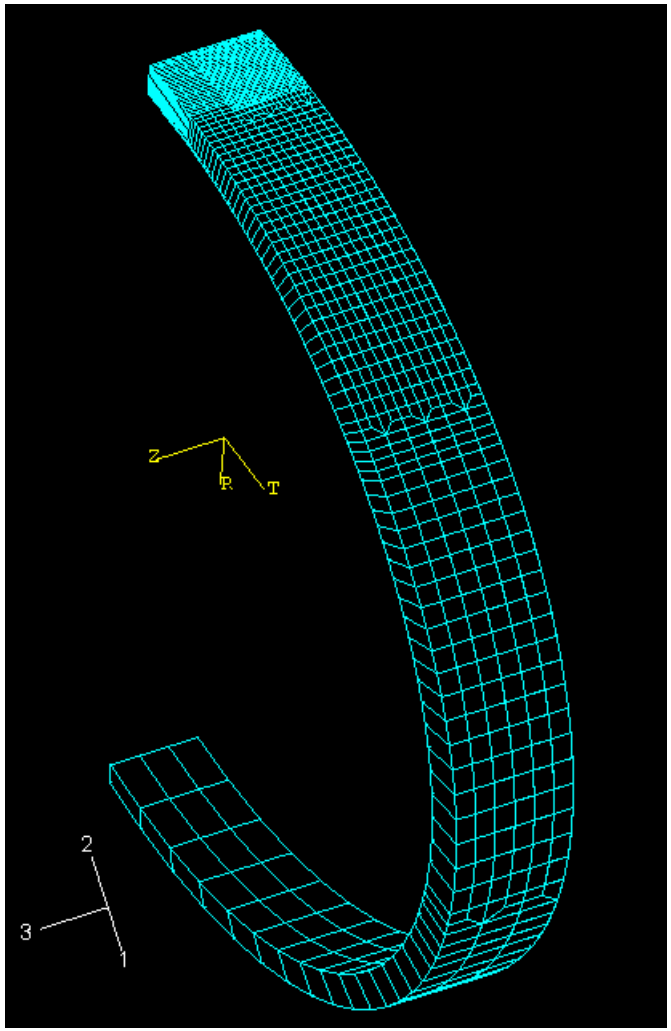
Blunt Nose Setup (2” x 5/16”)

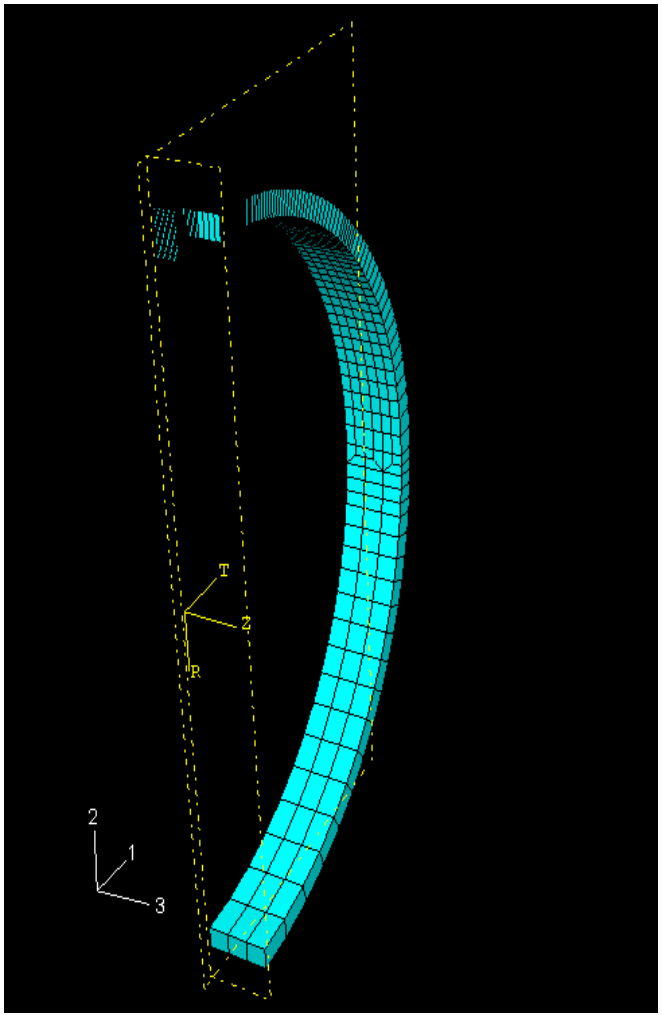


Kevlar Failure Mode (24 layers)

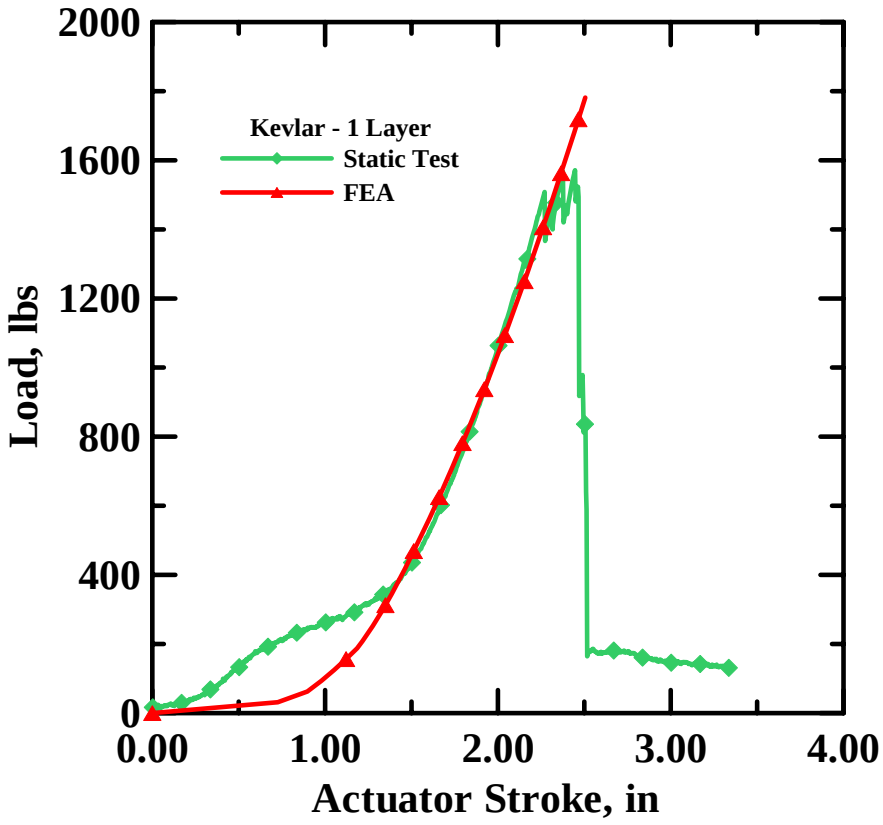
Zylon Failure Mode (24 layers)

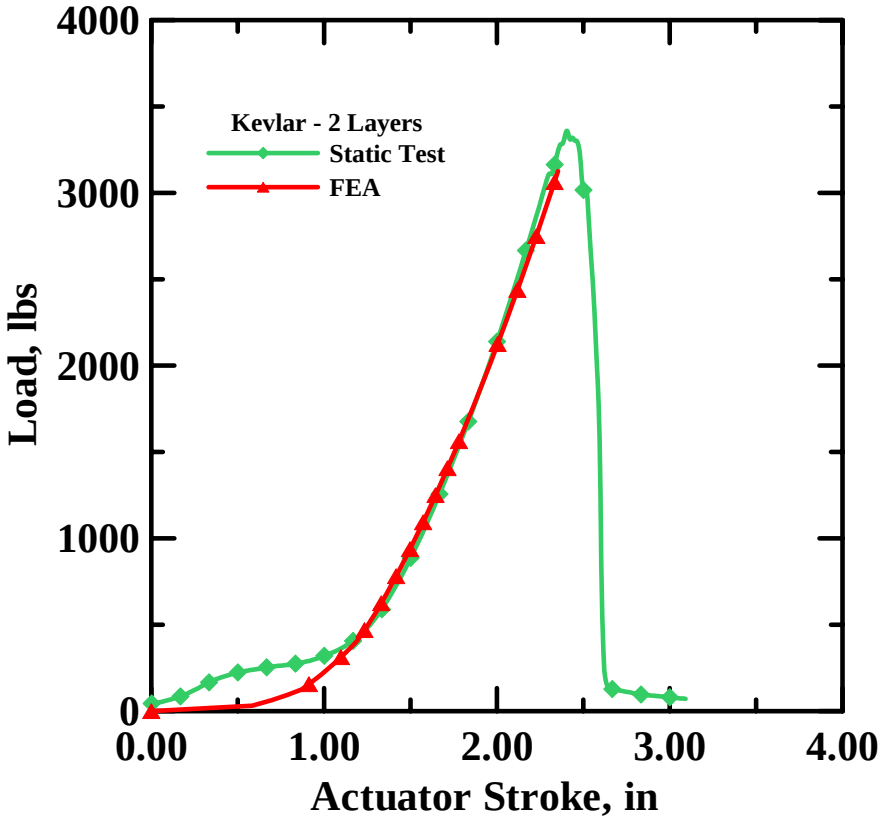
FE Model



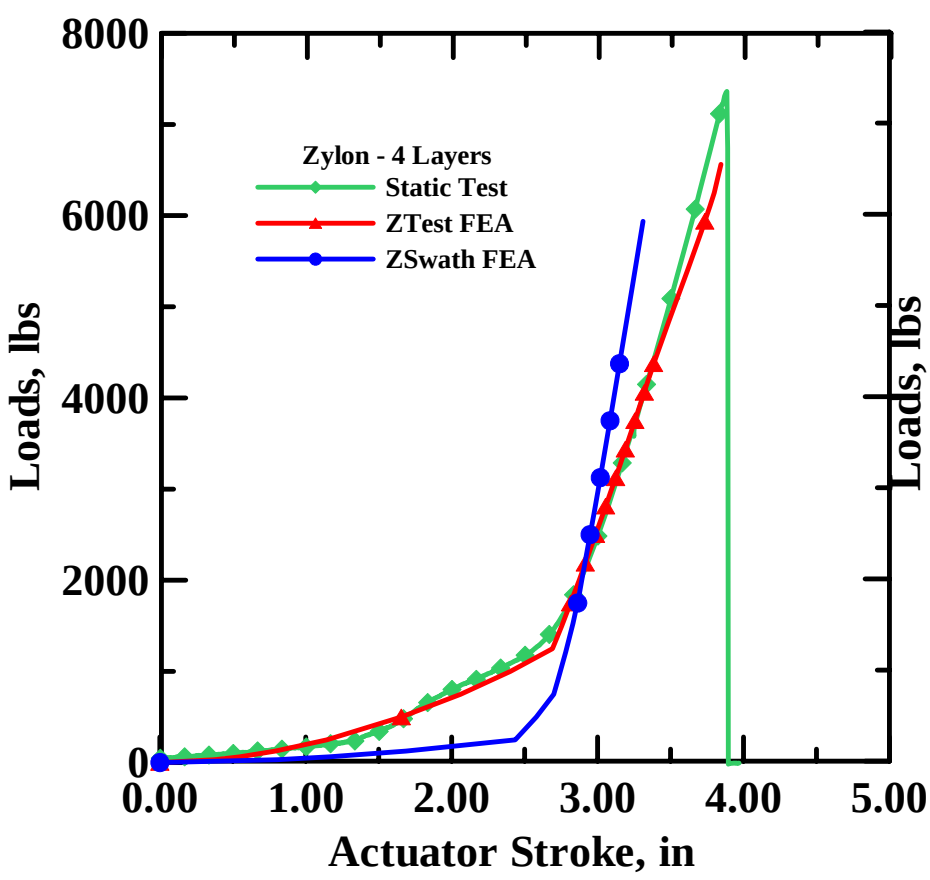


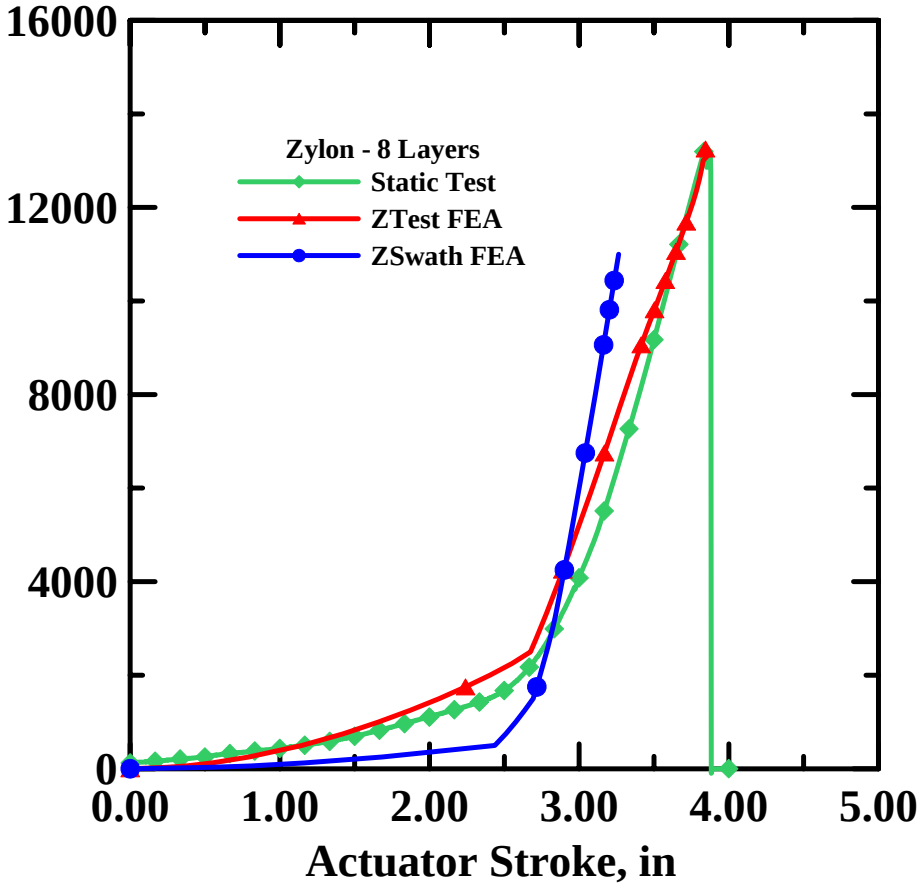
Kevlar: 1 & 2 Layer Tests



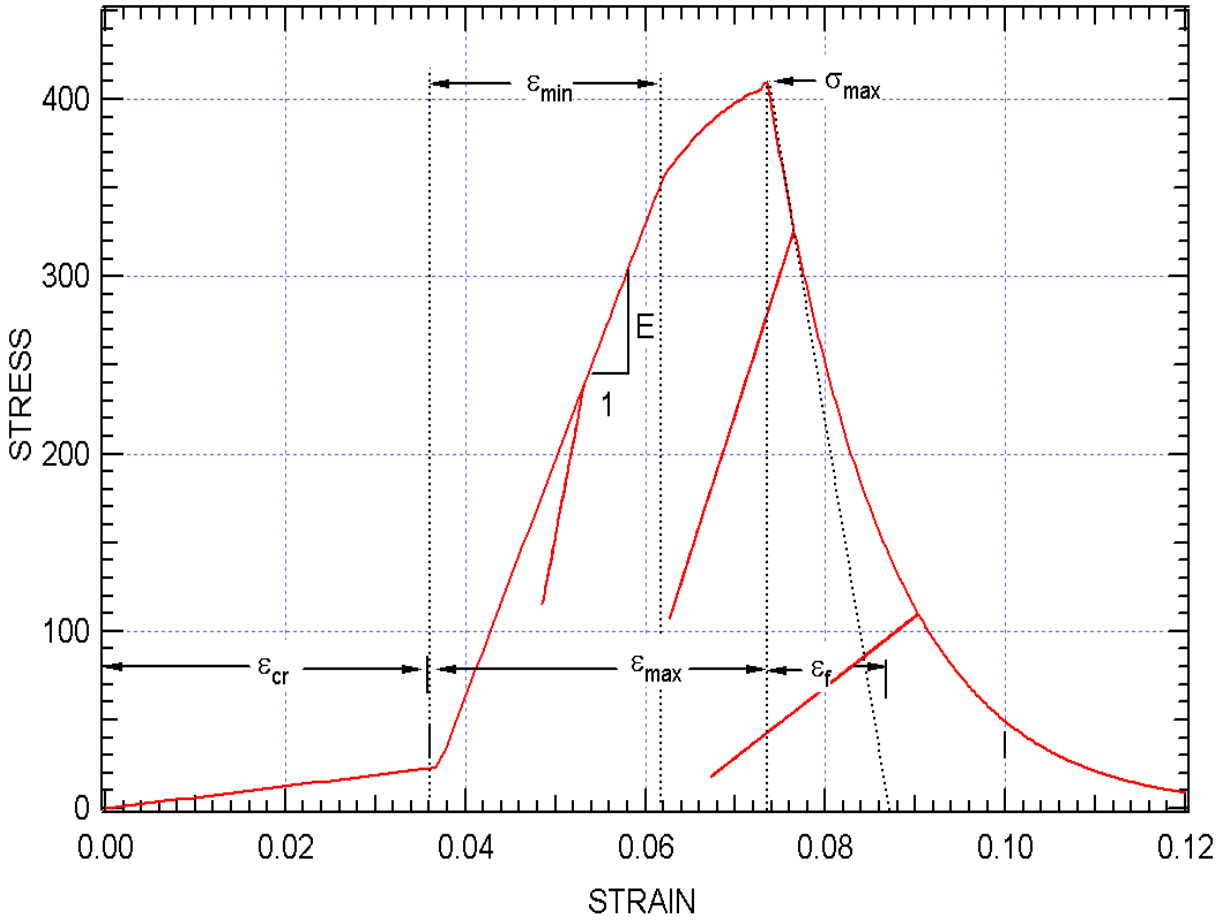


Zylon: 4 & 8 Layer Tests



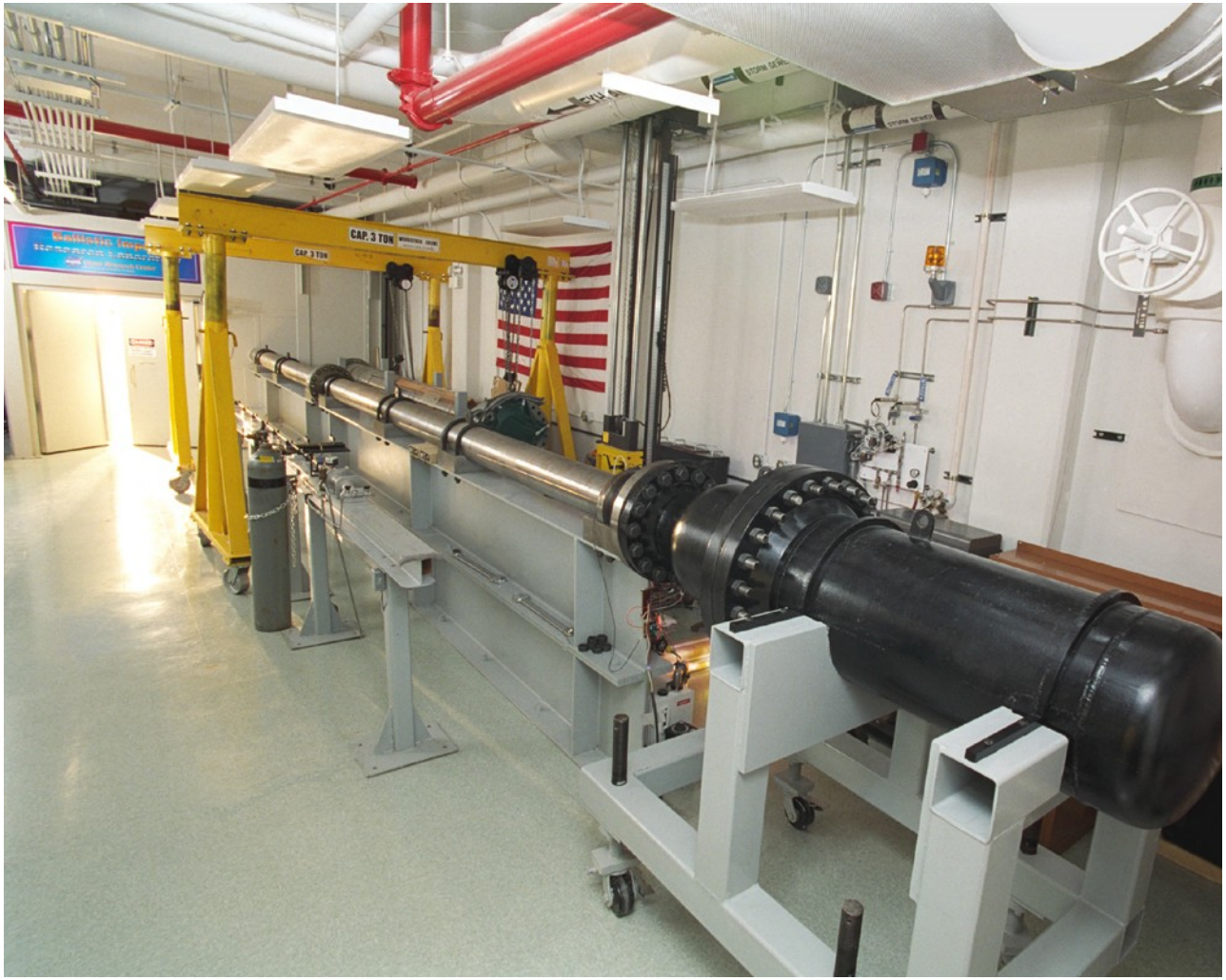


Ballistic Fabric Material Model



NASA-GRC
Ballistic Impact Testing

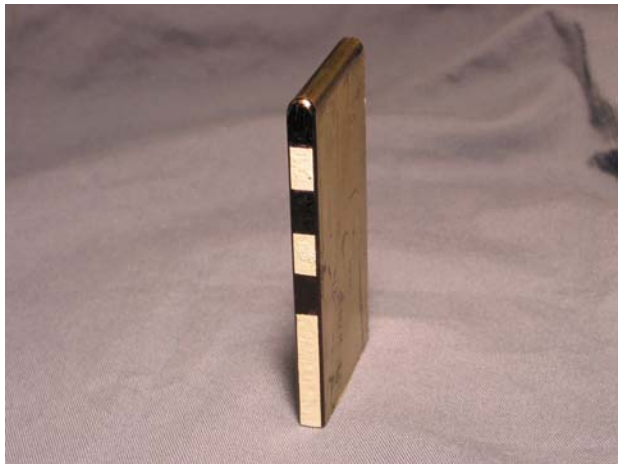
Test Setup

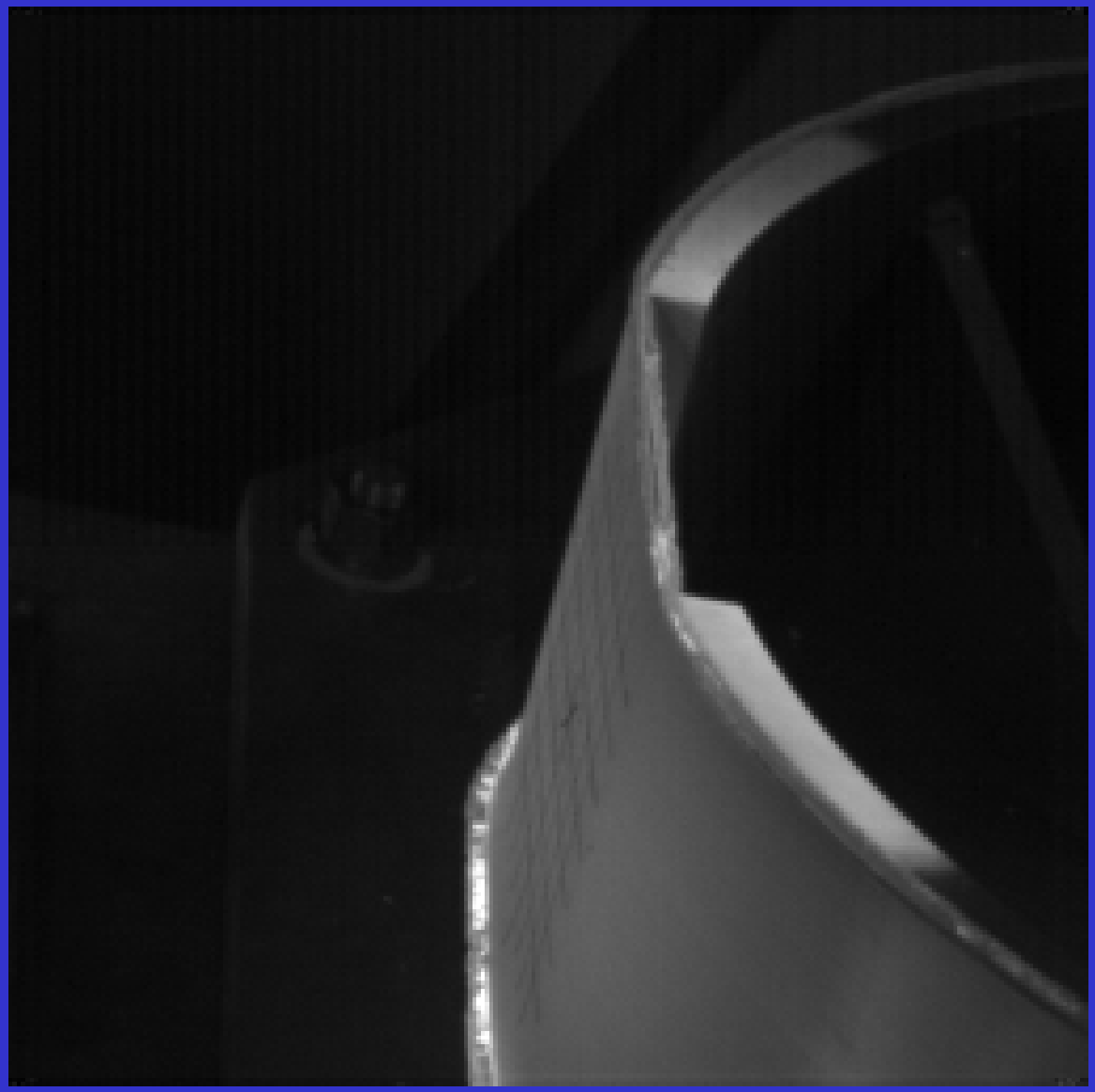


Test Setup

Projectile

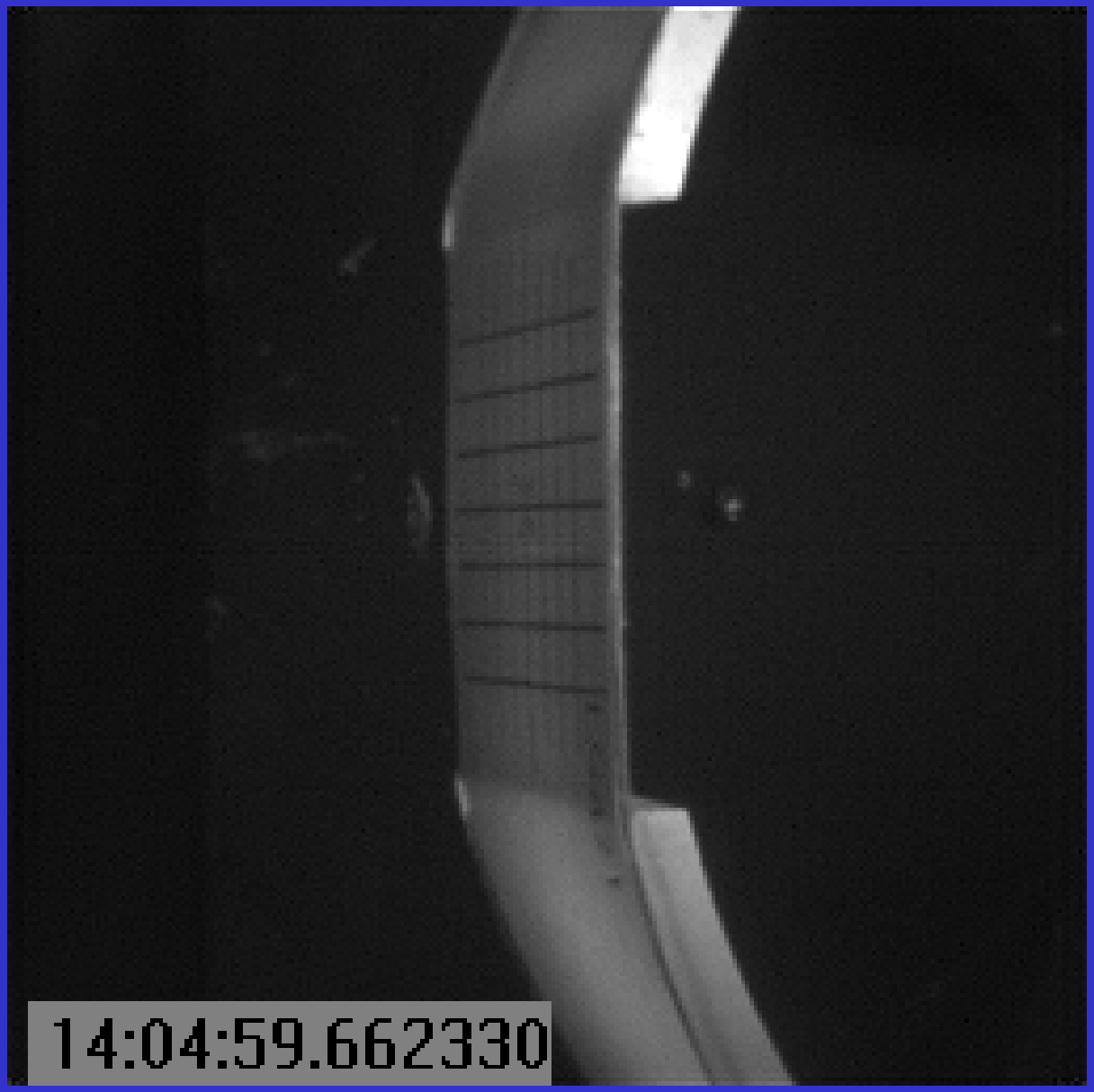
- 4” long, 2” high, 3/16” thick
- 304 SS
- Full radius leading edge
- Mass: 315 – 320 g





Test LG407. 24 Layer 500 d Zylon

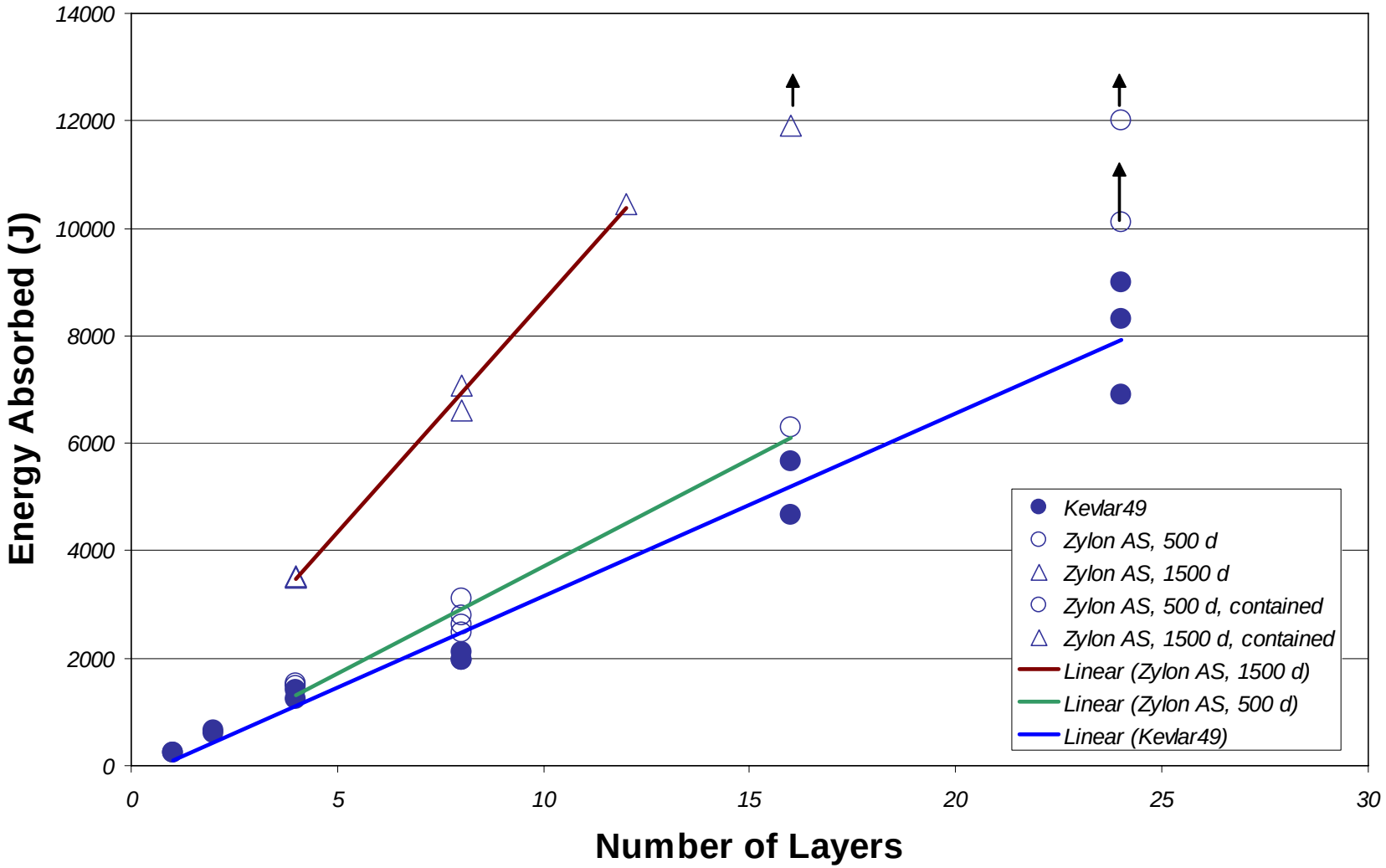
V = 904 ft/sec



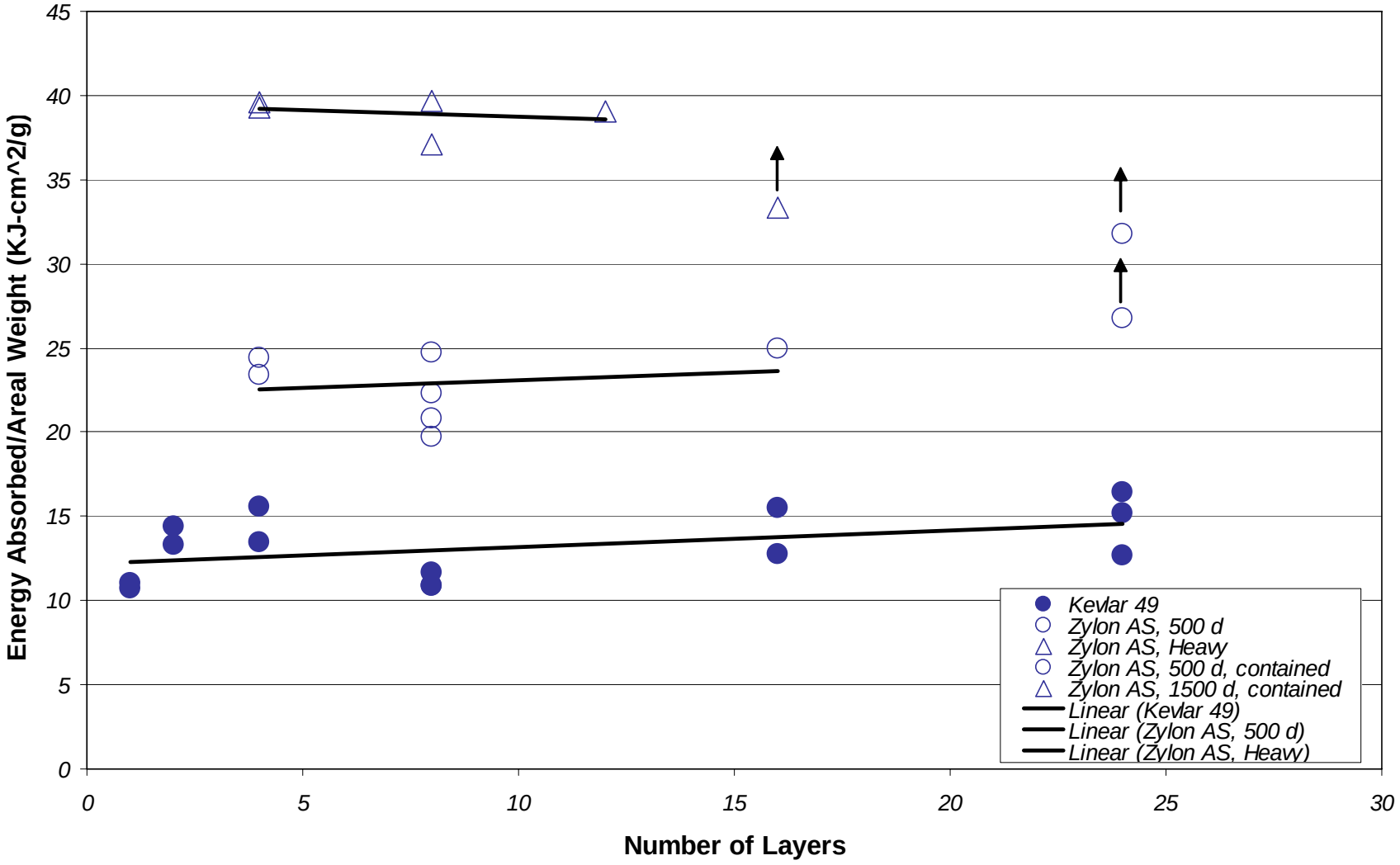
Test LG421. 8 Layer 1500 d Zylon

V = 859 ft/sec

Energy Absorbed



Fabric Normalized Energy Absorption



Conclusions

- Both light and heavy Zylon absorbed significantly more energy per unit areal weight than Kevlar
  - 500 denier Zylon absorbed approximately 70% more energy than the Kevlar
  - 1500 denier Zylon absorbed approximately 2.9 times as much energy as the Kevlar
- Small increase in maximum deflection from light to heavy Zylon
- Normalized energy absorbed did not increase significantly with number of layers

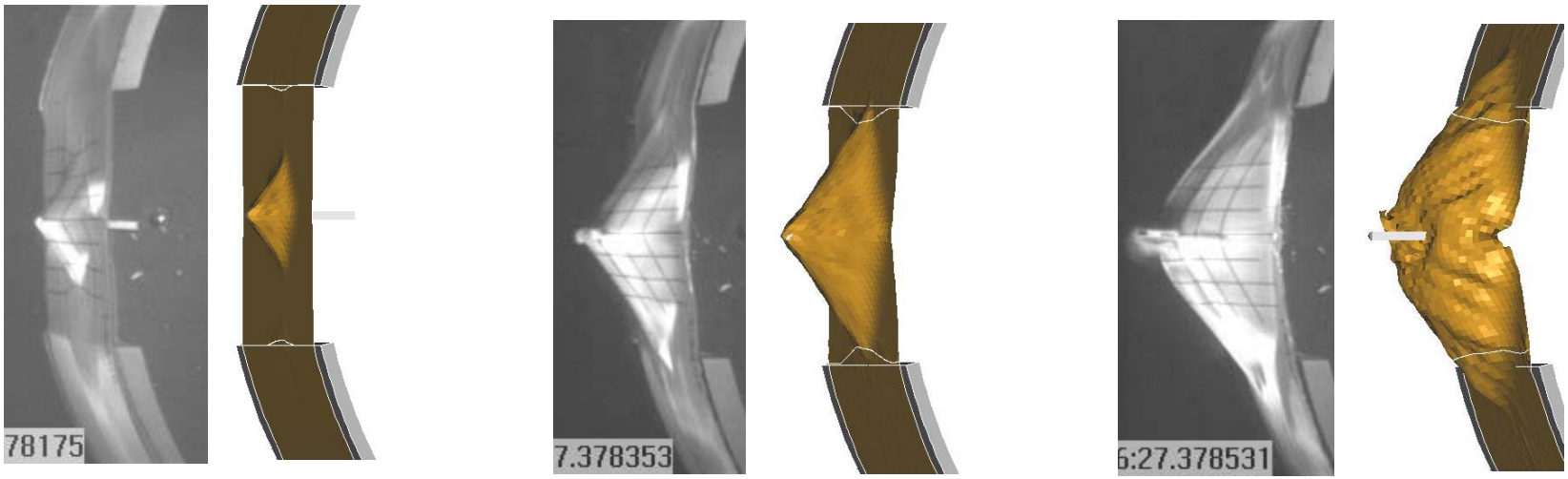
Conclusions

- Data available for validation of numerical models:
  - Projectile position vs. time
  - Projectile orientation
  - Fabric deflection
  - Impact velocity, exit velocity, energy absorbed

Honeywell and SRI

Generic Engine and Full-Scale Engine Modeling and Testing

NASA Test LG408 Verification

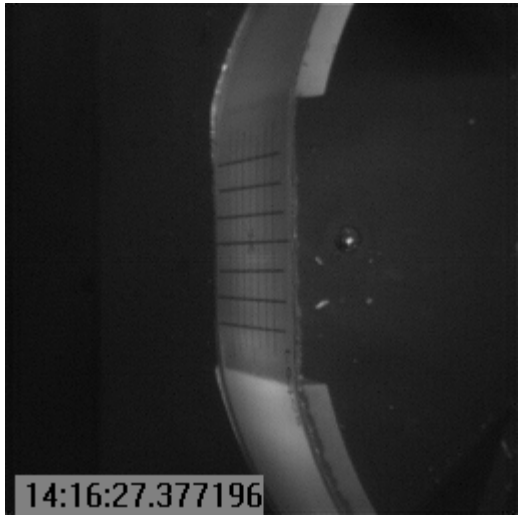


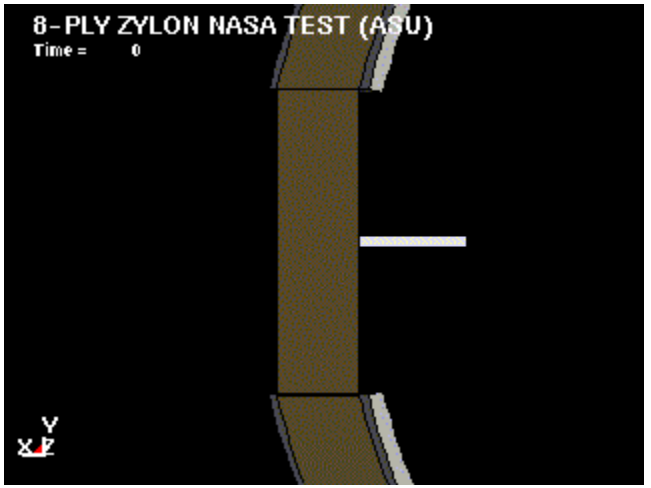
time=0.17 ms 0.35 ms 0.53 ms

- 8 ply Zylon
- Velocity
  - Expt: 904 -> 792 f/s
  - Model: 900 -> 778 f/s

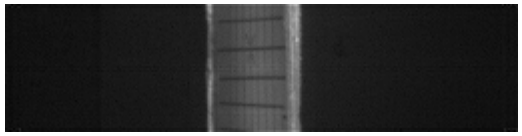
NASA Zylon Test Verification

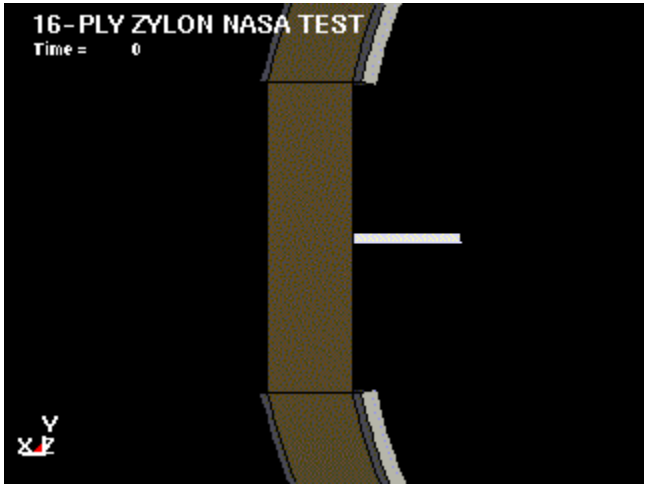
8 ply
(lg408)





16 ply
(lg426)

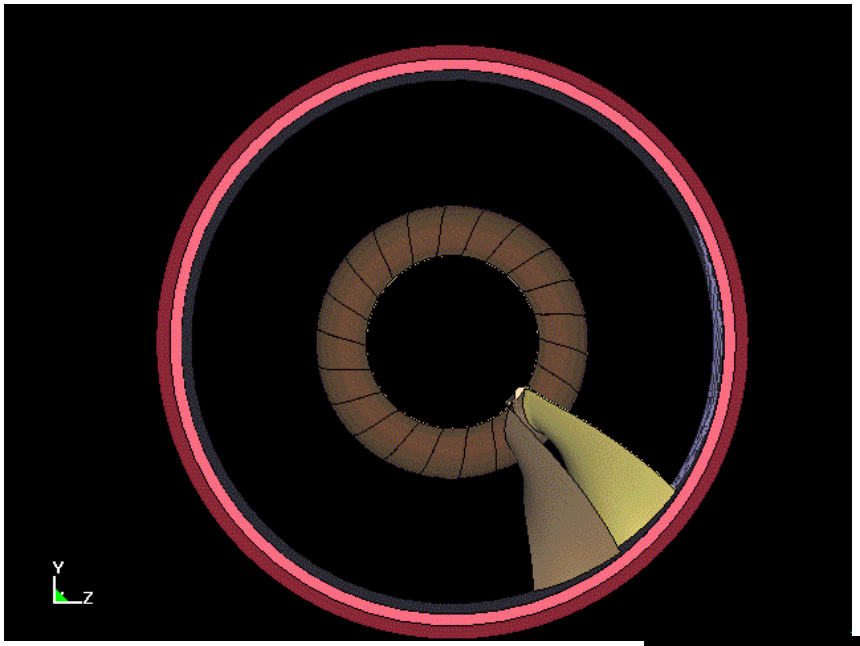


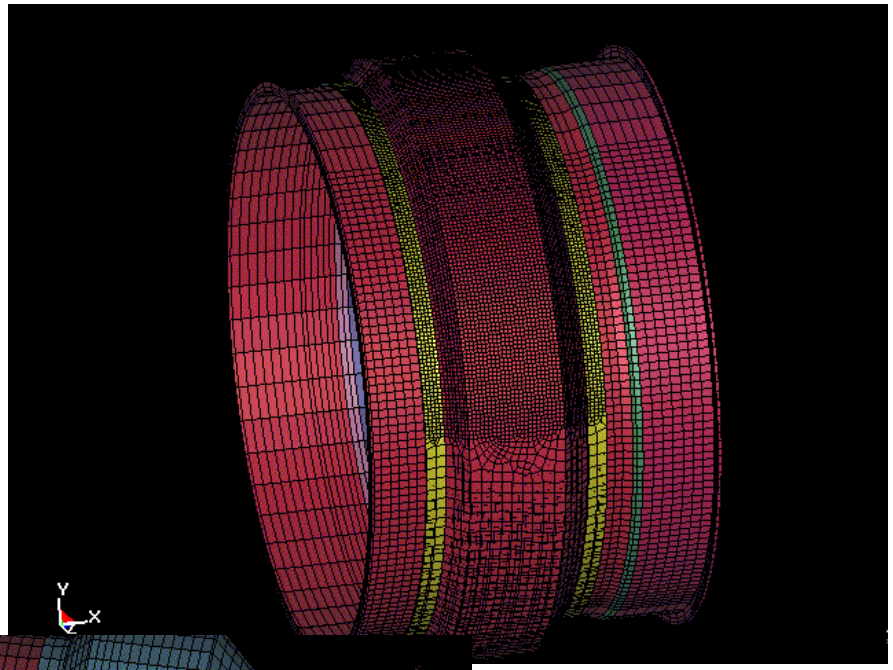


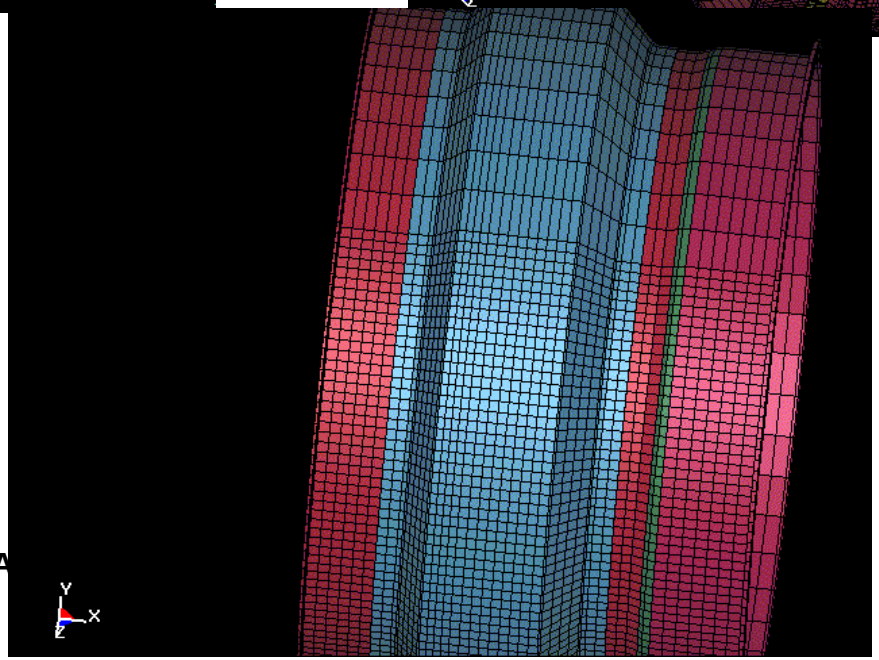
Engine Verification

- Work Conducted
  - AS900 Fan Blade Out (FBO) test conducted in 1999 to establish actual result
- Metrics
  - Qualitative comparison of LS-DYNA's ability to predict various failure modes to actual AS900 FBO test:
    - Opening angle of the containment housing, resting position of the blade
    - Deformed shape of the released blade
    - Integrity of the overall structure

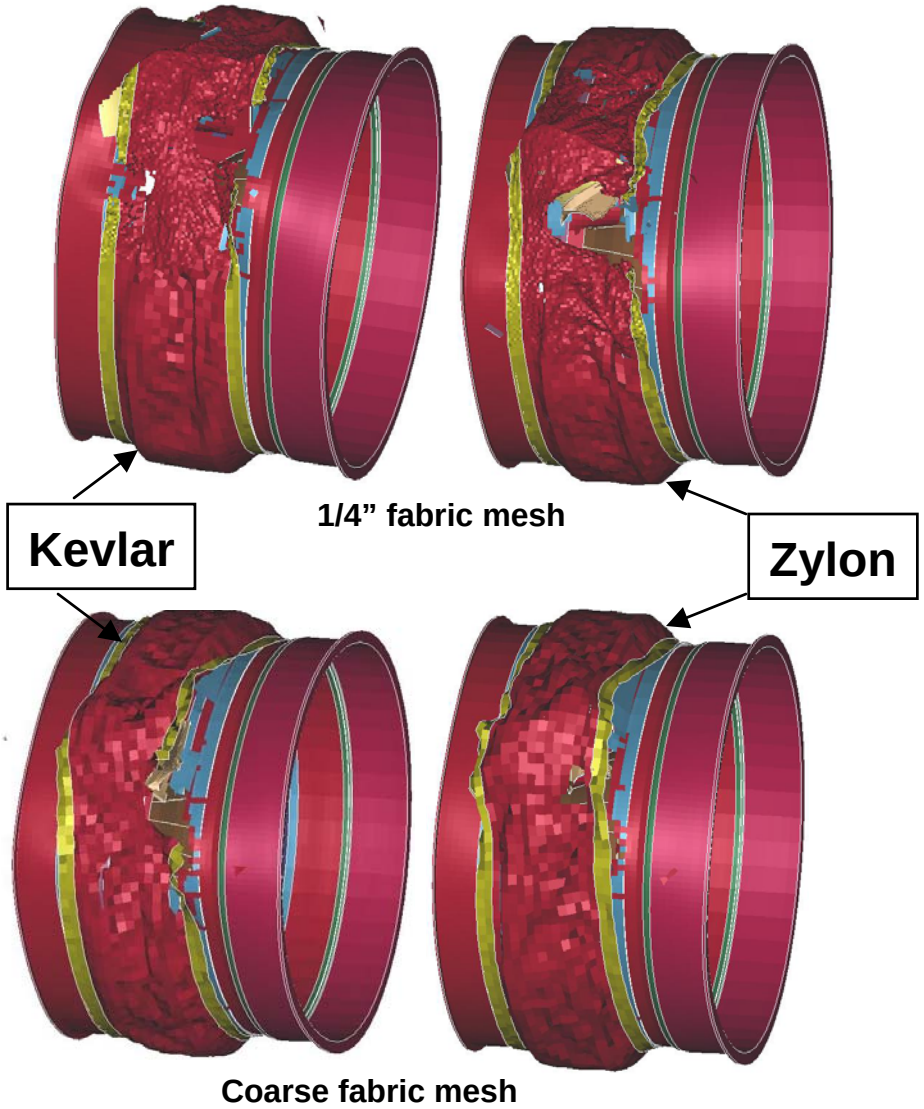
New Material Model (Kevlar)







Kevlar vs Zylon Containment Predictions



- Same model used, except fabric material properties
- Same number of fabric layers used
- Corresponding fabric thickenesses used for Kevlar and Zylon
- Similar containment capability predicted with Zylon substitution
- Consistent with ballistic test results, slightly higher properties of Zylon prevented local penetration. Some tearing of fabric predicted due to resulting higher loads
- Lower containment weight of ~5 lb with Zylon, due to density difference

Conclusions

- Fan blade-out event was successfully simulated
- Engine fan blade-out and containment tests results were simulated relatively well using new Kevlar model and single layer shell elements
- The prediction capability was significantly improved with new material model with respect due previously used methodology
- Comparison of Kevlar and Zylon for the same containment system revealed results consistent with ballistic test trend; weight reduction is possible if Kevlar is replaced by Zylon

Why Phase 2?

- Material Model
  - Tests to find all orthotropic material values
  - Consider heavier Zylon as an option
- Failure Model
  - Sharper projectiles
  - Varying roll, pitch and yaw with projectile contact with fabric

Why Phase 2?

- Computational Model
  - Multiple layers with friction
- Verification (QA)
  - More realistic engine FBO condition